Bulkley TSA inventory audit

Introduction

The Ministry of Forests conducts an inventory of each timber supply area (TSA) in British Columbia every 10 to 30 years—using standards and procedures that have been developed by the Resources Inventory Program—with regular updates to reflect changes in the timber volume due to growth and to depletions from harvesting and natural causes.

This report presents the results of an inventory audit performed within the Bulkley TSA. Located on the eastern drainage of the Skeena River in the interior portion of the Prince Rupert Forest Region, the Bulkley TSA covers an area of approximately 736 000 hectares and is administered from the Bulkley Forest District.

Purpose of the audit and application of the results

It is often asked, "How accurate is the current inventory?" To answer this important question, the Ministry of Forests has developed an inventory audit methodology specifically designed to test the overall accuracy of estimates of the total standing volume in each timber supply area.

This inventory audit methodology entails sampling three primary components of the inventory: mature forests, immature forests and non-forest areas.

The objective of the inventory audits program is to help identify TFLs or TSAs where the forest inventory needs attention. Enough samples are taken to ensure statistically reliable results for the TSA as a whole.

The amount of data collected, however, is not sufficient to make statistically reliable conclusions about specific areas or tree species. For example, any overall differences highlighted by the audit could result from problems with one tree species, from part of the land base (such as high elevation rather than lower elevation areas), from one age group of forest stands, or from a combination of these and other factors. As a consequence, general audit results cannot appropriately be used to adjust information about the forests currently available for timber harvesting since this area constitutes only a portion of the total forested area in the TSA.

The audits provide information that may be useful to the chief forester during determinations of the allowable annual cut—offering a general assessment of the uncertainty associated with mature timber volumes, immature site index, and the non-forest classification. However, the audit results cannot justifiably be used to make specific adjustments to growth and yield and other information used in timber supply analysis and allowable annual cut determinations.

Methods

Current inventory

There are 36 TSAs in British Columbia, varying in size from approximately 200 000 hectares to 13 000 000 hectares. Inventories of each TSA are conducted through a multistage process. Polygons (a boundary drawn around a forest stand of similar characteristics) are first delineated from 1:15 000 scale aerial photographs. Photo-interpretation is then used to produce data on a number of attributes for each polygon. These attributes include species composition, stand height, age, and crown closure. Timber volume is then estimated indirectly using the photo-interpreted variables and an empirical yield model.

To keep estimates current, inventories are regularly updated to account for forest growth, and for depletions due to harvesting, fire losses, and the impact of insects and disease. Empirical yield models, such as the Ministry of Forests Variable Density Yield Prediction (VDYP) computer model, are used to update the inventory for forest growth. Field visits, satellite imagery and aerial photographs may be used to update the inventory for depletion.

Inventory audit procedures

The inventory audit tests three components of the current inventory. The first component is the mature forested areas (forest stands greater than 60 years of age). The inventory audit tests the accuracy of the mature timber volume. The second component tested is immature stands (less than 60 years of age but greater than the silvicultural classification of free growing). The audit tests the accuracy of the site growth potential (site index) assignment for these stands. The third audit test is of the photo-classification accuracy of the non-forest classification component of the inventory (areas such as lakes, gravel pits and alpine meadows).

Mature component assessment criteria

Testing the mature component of the inventory compares the existing inventory's estimate of the mean mature volume per hectare for the TSA (called the *inventory volume*), and a new estimate of the mean mature volume per hectare for the TSA obtained from the audit samples (called the *audit volume*).

The difference between these two estimates is called the total bias. A test is conducted on this bias to determine if it is statistically significant. This test establishes whether there are detectable differences between the audit volume estimate and the inventory volume estimate, for the total forested area of the TSA.

Province of British Columbia
Ministry of Forests

If the total bias is found to be statistically significant, further analyses are conducted to determine if the specific source of bias within the inventory is one of the following:

- *classification bias:* This is caused by incorrectly estimating the polygon attributes; and
- *model bias:* This is caused by poor prediction from the yield model, which was developed for large areas of the province and was not designed for specific management units.

The analysis to determine the source of bias uses an estimate of the mean mature volume per hectare for the TSA called the *ground attribute volume*. This is calculated from audit sample attributes (stock and stand table estimates of species composition and stocking, and ground-based averages of top height and age), along with crown closure taken from the original map label, using the yield prediction model. The difference between the ground attribute volume estimate and the audit volume estimate approximates the bias associated with the yield model. The difference between the audit volume estimate and the inventory volume estimate not accounted for by the model bias approximates the bias associated with the inventory classification attributes. Once the source is identified, further analyses may be done on the attributes or the model itself.

Immature component assessment criteria

Accuracy of the inventory classification for immature stands is tested by examining the site index assignment. Since the immature forest stand site index provides an estimate of site productivity, its accuracy affects the projection of long-term harvest levels.

Data gathered is examined to determine how closely the audit and inventory site indices match for individual samples, and to explore potential trends.

Non-forest component assessment criteria

The audit test for the non-forest component of the inventory assesses the accuracy of the non-forest classification assignment. An air photo interpreter certified by the Ministry of Forests compares the non-forest inventory classification to a suitably-scaled forest cover aerial photograph. Classification accuracy is rated from a point scoring scheme to determine an overall accuracy percentage. The acceptance criteria for this test is 85% or higher.

Bulkley TSA audit sampling procedures

The Bulkley sample uses updated maps based on an inventory originally conducted between 1974 and 1976, with a classification reinventory done in 1988. A list of all polygons identified on these maps was produced and sorted on a number of stand characteristics (site quality, age, and species group). Polygons were systematically selected from this list by a process designed to produce a representative sample of the TSA.

For the mature forested component of the inventory audit, a random sample of 50 forested polygons from the total forested area in the TSA were selected for sampling.

Up to four full-measure prism plots, and five count plots, were established within each of the 50 sample polygons. The plots were located systematically, using a square grid and a random start point. The grid interval distance varied with polygon size. To reduce sample costs for large or irregular polygons, only a randomly selected portion of the polygon was sampled. In total, about 200 full-measure and 250 count plots were established. Field data collection and compilation followed Ministry of Forests cruising and cruise compilation procedures. The objective was to obtain audit volumes that were comparable (in terms of utilization standards and merchantability definitions) to the inventory volumes that are produced from the VDYP yield model.

The VDYP system produces net merchantable volume per hectare defined as stem volume inside bark of all live trees excluding a 10 cm diameter inside-bark top, a 30 cm high stump, and decay (as estimated from Ministry loss factors). Dead potential and veteran trees are not included in the VDYP system volume estimates. This volume is calculated for a utilization standard defined as all live trees of 12.5+ cm dbh. When considering the audit results, it should be noted that there are some differences between the utilization standards applied in the audit and those used operationally.

The audit volume estimates were then compared to the inventory volume estimates (from VDYP) to test the validity of the current inventory. Ratios of audit volume to inventory volume were calculated to test for significant differences. The precision of the inventory volume estimates—how well the inventory volume estimate corresponds to the audit volume estimate on a sample by sample basis—were assessed by measuring their statistical correlation. The data was then post-stratified to detect trends related to the operable and inoperable forested land base distribution of the sampled polygons.

From the immature forested component, a random sample of 20 polygons were selected for sampling. Up to six inventory ground calls were established within each of the 20 sample polygons. The plots were located along a single transect line that was considered representative of the site productivity (site index) of the stand. In total, approximately 120 ground calls were established. Field data collection followed the standard Ministry of Forests inventory ground call procedures. The location of the sample transect was subjective. Since the magnitude of bias caused by this process is unknown, the reported results and their interpretations for the immature forested component of the inventory should be used with caution.

For the audit of the non-forest component of the inventory, a random sample of 30 non-forest polygons were selected. Standard Ministry of Forests inventory air photo classification techniques were used to compare the 30 non-forest polygon classification assignments to corresponding air photo checks.

Inventory audit results

Analysis of mature volumes

The results of the inventory audit for mature volume statistical analyses at the 12.5+ cm dbh utilization limit for the total forested area are given in Table 1.

	Audit Volume Estimate	Inventory Volume Estimate
Number of Samples	50	50
Mean (m^3/ha)	269	277
Coefficient of variation (%)	40	35
Standard error	15.26	13.86
Sampling Error (%)	11.4	10.1
95% Confidence Interval (m^3/ha)	238-299	249-305

Correlation coefficient r = 0.274
Ratio of means (audit/inventory volume estimates) = 0.97

Table 1: Statistics for the audit volume and inventory volume estimates at 12.5 cm+ dbh utilization for the Bulkley TSA.

audit volume estimate	238	269	299
inventory volume estimate	249	277	305

Table 2: Bar graph representation of 95% confidence intervals in m^3/ha

The calculated correlation coefficient of 0.274 for the audit and the inventory volume estimates indicates a poor relationship among the individual samples. There is an 8 m^3/ha difference between the means of the inventory estimate for mature volume (277 m^3/ha) and the audit estimate (269 m^3/ha). Although this comparison shows there is no statistically significant difference, the poor correlation between the estimates indicates a high degree of variation at the individual polygon level.

Since there was no statistical difference between the two estimates the ground attribute volume was not calculated.

Analysis of operable and inoperable volumes

To provide audit results more likely to be applicable to the timber supply planning process, an approximation was made of the forested areas considered currently available for timber harvesting (called *operable* areas). The audit results were post-stratified based on this approximation. The results of the inventory audit for samples in the operable forested areas in the TSA are given in Table 3. There were 18 samples in inoperable forested areas. Because of the high variability and restrictive nature of conclusions associated with this small sample size, volume estimates from inoperable forested areas are not shown.

	Operable Audit Volume Estimate	Operable Inventory Volume Estimate
Number of Samples	32	32
Mean (m^3/ha)	285	311
Coefficient of variation (%)	34	28
Standard Error	17.04	15.50
Sampling Error (%)	12.2	10.2
95% Confidence Interval	250-320	280-343

Operable ratio of means = 0.92

Table 3: Statistics for the operable audit and inventory volume estimates at 12.5+ cm dbh utilization for the Bulkley TSA.

audit volume estimate	250	285	320
inventory volume estimate	280	311	343

Table 4: Bar graph representation of 95% confidence intervals in m^3/ha for the operable forested area.

For the 32 samples located within operable forested areas, the mean audit volume was 285 m^3/ha and the corresponding inventory volume was 311 m^3/ha. The difference between these two esimates was not statistically significant. The sample size of 18 in inoperable forested areas was insufficient to allow any meaningful comparisons to be made.

Analysis of immature inventory classification

Out of 20 stands sampled in the field, one stand was not assessed a site index because it was found to be a mature stand. Of the remaining 19 stands, the inventory correctly identified site index within ± 3 m of the audit site index for nine stands. The inventory site index was more than 3 m lower than the audit site index for nine stands, and more than 3 m higher for one stand.

Analysis of non-forest inventory classification

Thirty stands classified as non-forest were assessed for their inventory assignment accuracy. The resulting score was 87%, which meets the provincial minimum standard of 85%.

Discussion and conclusions

The objective of the inventory audit in the Bulkley TSA was to assess the overall accuracy of the current Ministry of Forest inventory. The mature, immature and non-forest components were tested.

The results of the audit for the mature component of the inventory suggest that the inventory is statistically acceptable. However, the correlation between the audit and the inventory volumes is poor. This suggests a potential

lack of consistency between the audit and inventory volume estimates. Conclusions regarding the acceptability of the inventory should be viewed with caution. The Bulkley TSA has undergone a new inventory since this audit took place. The new inventory will be assessed for accuracy using the information obtained by this audit.

Audit results for the immature component of the inventory suggests an acceptable level of accuracy for site index assignment for young stands.

The audit assessment of the non-forest classification in the TSA found it to be within provincial standards.

Glossary

accuracy: A measure of the closeness of an estimate to the true value.

allowable annual cut: The rate of timber harvesting specified for an area of land.

analysis unit: The basic building block around which inventory data and other information are assembled for use in forest planning models. Analysis units represent the general level of aggregation, or detail, at which a timber supply analysis is carried out. They are normally defined by tree species and site qualities.

bias: The quality of a measurement device or procedures that tends to result in a systematic misrepresentation of what is being measured.

coefficient of variation: A relative measure of the variation of the population calculated as the ratio between the standard deviation and the mean value.

confidence interval: The range of values within which the population parameter is expected to lie.

confidence level: The estimated probability that a population parameter lies within a given confidence interval.

correlation coefficient: A measure of the relationship between two variables. A value of 0 for the correlation coefficient indicates a random relationship whereas a value of ±1 indicates a perfect positive or negative linear correspondence.

diameter at breast height (dbh): The stem diameter (outside-bark) of a tree measured at breast height (1.3 metres above the point of germination) to the nearest millimetre.

field visitations: Ground level field procedures designed to provide physical verification of polygon inventory attributes.

free growing (crop): A crop of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees.

inoperable: Refers to areas having merchantable timber that cannot be harvested economically using current harvesting technology because of some physical barrier (such as a hanging valley), and to areas containing small patches of overmature timber surrounded by large areas of young stands.

mean: The average value of a set of observations.

pre-inventory assessments: Pre-inventory analyses are inventory activities to evaluate the existing forest inventory as the basis for deciding whether to re-inventory or update the current inventory, and to document the existing inventory, maps, and photos to support the execution of the reinventory or update if required.

ratio estimate: The ratio between two different estimates.

representative: The quality of a sample having the same characteristics as the population from which it is selected.

sampling: The process of selecting observations.

sampling error: The error attributed to sampling procedures.

significant difference: An expression used in reference to the results of a statistical test in which either two or more estimates are compared or an estimate is compared to a fixed value. If the observed difference is greater than what might be expected as a chance occurrence due to the sampling procedures, the difference is said to be statistically significant.

site index: A measure of site productivity. Site indices are based on tree height as a function of stand age and are usually expressed graphically as site index curves. A number of site index curves have been developed for British Columbia's major commercial tree species.

standard error: An expression of the absolute variability of an estimate.

standard deviation: A measure of the variation of the population.

timber supply analysis: The technical process of amalgamating land management information into computer systems that predict the amount of timber available for harvest over given time periods.

timber supply area: An integrated resource management unit established in accordance with section 6 of the *Forest Act*.

tree farm license: An integrated resource management unit established in accordance with section 28 of the *Forest Act*.

For more information

For more information or to obtain other inventory audit reports, contact: Director, Resources Inventory Branch, 722 Johnson Street, Victoria, B.C., Canada V8W 3E7, 387-1314, fax 387-5999, or e-mail to RIBinfo@galaxy.gov.bc.ca.

Bulkley TSA Inventory Audit

Table of Contents

Introduction 1
Purpose of the audit and application of the results 1
Methods 1
- Current inventory 1
- Inventory audit procedures 2
- Mature component assessment criteria 2
- Immature component assessment criteria 3
- Non-forest component assessment criteria 3

Bulkley TSA audit sampling procedures 4
Inventory audit results 5
- Analysis of mature volumes 5
- Analysis of operable and inoperable volumes 7
- Analysis of mature species classification 9
- Analysis of immature inventory classification 10
- Analysis of non-forest inventory classification 12

Discussion and conclusions 12
References 12
Appendices 12
Glossary 19

Introduction

The Ministry of Forests conducts an inventory of each timber supply area (TSA) in British Columbia every 10 to 30 years – using standards and procedures that have been developed by the Resources Inventory Program – with regular updates to reflect changes in the timber volume due to growth and depletions due to harvesting and natural causes.

This report presents the results of an inventory audit performed within the Bulkley TSA. Located on the eastern drainage of the Skeena River in the interior portion of the Prince Rupert Forest Region, the Bulkley TSA covers an area of approximately 736 000 hectares and is administered from the Bulkley Forest District.

Purpose of the audit and application of the results

It is often asked, "How accurate is the current inventory?" To answer this important question, the Ministry of Forests has developed an inventory audit methodology specifically designed to test the overall accuracy of estimates of the total standing volume in each timber supply area.

This inventory audit methodology entails sampling three primary components of the inventory: mature forests, immature forests and non-forest areas.

The objective of inventory audits is to help estimate the statistical precision and bias of the forest inventories in TFLs and TSAs. Enough samples are taken to ensure statistically reliable results for the TFL or TSA as a whole.

The amount of data collected, however, is not sufficient to make statistically reliable conclusions about specific areas or tree species. For example, any overall differences highlighted by the audit could result from problems with one tree species, from part of the land base (such as high elevation rather than lower areas), from one age group of forest stands, or from a combination of these and other factors. As a consequence, general audit results cannot appropriately be used to adjust information about the forests currently available for timber harvesting since this area constitutes only a portion of the total forested area in the TSA.

The audits provide information that may be useful to the chief forester during determinations of the allowable annual cut – offering a general assessment of the uncertainty associated with mature timber volumes, immature site index, and the non-forest classification. However, the audit results cannot justifiably be used to make specific adjustments to growth and yield and other information used in timber supply analysis and allowable annual cut determinations.

Methods

Current inventory

There are 37 TSAs in British Columbia, varying in size from approximately 200 000 hectares to 13 000 000 hectares. Inventories of each TSA are conducted through a multistage process. Polygons (a boundary drawn around a forest stand of similar characteristics) are first delineated from 1:15 000 scale aerial photographs. Photo-interpretation is then used to produce data on a number of attributes for each polygon. These attributes include species composition, stand height, age, and crown closure.

Timber volume is then estimated indirectly using the photo-interpreted variables and an empirical yield model.

To keep estimates current, inventories are regularly updated to account for forest growth, and for depletions due to harvesting, fire losses, and the impact of insects and disease. Empirical yield models, such as the Ministry of Forests Variable Density Yield Prediction (VDYP) computer model, are used to update the inventory for forest growth. Field visits, satellite imagery and aerial photographs may be used to update the inventory for depletion.

Inventory audit procedures

The inventory audit tests three components of the current inventory. The first component is the mature forested areas (forest stands greater than 60 years of age). The inventory audit tests the accuracy of the mature timber volume and also examines the species classification accuracy for the mature forested areas. The second component tested is immature stands (less than 60 years of age but greater than the silvicultural classification of free growing). The audit tests the accuracy of the site growth potential (site index) assignment and the species classification accuracy for these stands. The third audit test is of the photo-classification accuracy of the non-forested classification component of the inventory (areas such as lakes, gravel pits and alpine meadows).

Mature component assessment criteria

Testing the mature component of the inventory compares the existing inventory's estimate of the mean mature volume per hectare for the TSA (called the *inventory volume*), and a new estimate of the mean mature volume per hectare for the TSA obtained from the audit samples (called the *audit volume*).

The difference between these two estimates is called the total bias. Two tests are conducted on this bias to determine if it is statistically significant. These tests establish whether there are detectable differences between the audit volume estimate and the inventory volume estimate, for the total forested area of the TSA. In the first test, the ratio of the means of the two volume estimates and the confidence interval for this ratio are calculated. If the value 1.0 is within this 95% confidence interval, the inventory volume is considered acceptable. In the second test, a paired sample t-test (Walpole 1974) is used to determine whether the mean difference between the two estimates is statistically significant.

If these two tests find the total bias to be statistically significant, further analyses are conducted to determine if the specific source of bias within the inventory is one of the following:

- *classification bias:* This is caused by incorrectly estimating the polygon attributes; and/or
- *model bias:* This is caused by poor prediction from the yield model, which was developed for large areas of the province and was not designed for specific management units.

The analysis to determine the source of bias uses an estimate of the mean mature volume per hectare for the TSA called the *ground attribute volume*. This is calculated from audit sample attributes (stock and stand table estimates of species composition and stocking, and ground-based averages of top height and age), along with crown closure

taken from the original map label, using the yield prediction model. The difference between the ground attribute volume estimate and the audit volume estimate approximates the bias associated with the yield model. The difference between the audit volume estimate and the inventory volume estimate not accounted for by the model bias approximates the bias associated with the inventory classification attributes. Once the source is identified, further analyses may be done on the attributes or the model itself.

Note that the analyses using ground attribute volume can only approximate the model and classification bias. Model and classification bias are usually confounded to some degree and are difficult to separate. For example, there is model error inherently associated with the inventory attributes since inventory heights are updated or projected. There may also be errors related to stand dynamics that are influenced by the length of time between the original inventory and the audit (the projection period). In addition, model error may exist as a result of a bias associated with the plots used to fit the VDYP model. Analyses using ground attribute volume cannot be used to precisely identify the source of bias in an inventory, however, they may be useful to indicate potential areas for further investigation.

The species classification accuracy for the mature component is also examined. Species composition is generally determined by visually estimating percent crown cover by species from aerial photographs. For analysis and general reporting purposes these species types are then combined into 17 broad aggregations of species groupings called growth type groups. Growth type groups are the primary basis for species type stratification used in the timber supply analysis process. The accuracy of the species composition attribute can be judged by comparing how often the inventory growth type group classification agrees with the audit sample classification. A statistical measure called the K statistic is used to evaluate this level of agreement (Cohen 1960). The K statistic compares the observed level of agreement (the proportion of growth type group matches) with the expected level of agreement. A "high level of agreement" for the K statistic is based on a 5% significance level. It is assumed that the audit samples represent the entire polygon and that a ground based species composition derived from a volume summary is compatible with a photo based species estimate.

Immature component assessment criteria

Accuracy of the inventory classification for immature stands is tested by examining the site index assignment. Since the immature forest stand site index provides an estimate of site productivity, its accuracy affects the projection of long-term harvest levels.

Data gathered is examined to determine how closely the audit and inventory site indices match for individual samples, and to explore potential trends.

The species classification accuracy for the immature component of the inventory is also examined. Using the same approach that was outlined in the mature component section, a K statistic is used to determine the level of agreement in the growth type group classification between the audit and the inventory.

Non-forest component assessment criteria

The audit test for the non-forest component of the inventory assesses the accuracy of the non-forest classification assignment. An air photo interpreter certified by the Ministry of Forests compares the non-forest inventory classification to a suitably-scaled forest cover aerial photograph. Classification accuracy is rated from a point scoring scheme to

determine an overall accuracy percentage. The acceptance criteria for this test is 85% or higher.

Bulkley TSA audit sampling procedures

The Bulkley TSA sample uses updated maps based on an inventory originally conducted between 1974 and 1976, with a classification reinventory done in 1988. A list of all forested polygons identified on these maps was produced and sorted on a number of stand characteristics (site quality, age, and species group). Polygons were systematically selected from this list by a process designed to produce a representative sample of the TSA.

For the mature forested component of the inventory audit, a random sample of 50 forested polygons from the total forested area in the TSA base were selected for sampling.

Up to four full-measure prism plots, and five count plots, were established within each of the 50 sample polygons. The plots were located systematically, using a square grid and a random start point. The grid interval distance varied with polygon size. To reduce sample costs for large or irregular polygons, only a randomly selected portion of the polygon was sampled. In total, about 200 full-measure and 250 count plots were established. Field data collection and compilation followed Ministry of Forests cruising and cruise compilation procedures. The Schumacher volume function was used in the volume compilation process. The objective was to obtain audit volumes that were comparable (in terms of utilization standards and merchantability definitions) to the inventory volumes that are produced from the VDYP yield model.

The VDYP system produces net merchantable volume per hectare defined as stem volume inside bark of all live trees excluding a 10 cm diameter inside-bark top, a 30 cm high stump, and decay (as estimated from Ministry loss factors). This volume is calculated for a utilization standard defined as all live trees of 12.5+ cm dbh. Dead potential and veteran trees are not included in the VDYP system volume estimates. When considering the audit results, it should be noted that there are some differences between the utilization standards applied in the audit and those used operationally.

The audit volume estimates were then compared to the inventory volume estimates (from VDYP) to test the validity of the current inventory. The ratio of mean audit volume to mean inventory volume, and the confidence interval for this ratio, were calculated to test for significant differences. In addition, a paired sample t-test was also performed. The precision of the inventory volume estimates—how well the inventory volume estimate corresponds to the audit volume estimate on a sample by sample basis—were assessed by measuring their statistical correlation. A K statistic was calculated to determine if the observed level of growth type group agreement between the inventory and the audit was statistically significant. The data was then post-stratified to detect trends related to the operable and inoperable forested land base distribution of the sampled polygons.

From the immature forested component, a random sample of 20 polygons were selected for sampling. Up to six inventory ground calls were established for each of the 20 polygons. The plots were located along a single transect line that was considered representative of the site productivity (site index) of the stand. In total, approximately 120 ground calls were established. Field data collection followed the standard Ministry

of Forests inventory ground call procedures. The location of the sample transect was subjective. Since the magnitude of bias caused by this process is unknown, the reported results and their interpretations for the forested component of the inventory should be used with caution.

Site index was calculated using the site index curves in the most recent version of Freddie (the Ministry of Forests' Site Index Estimation Program), using total age (or breast height age where available) and top height. This audit site index was compared with the inventory site index indicated on the Ministry of Forests' forest cover attributes file (i.e. Forest Inventory Planning (FIP) file). As for the mature component, a K statistic was used to evaluate the growth type group classification.

For the audit of the non-forest component of the inventory, a random sample of 30 non-forest polygons were selected. Standard Ministry of Forests inventory air photo classification techniques were used to compare the 30 non-forest polygon classification assignments to corresponding air photo checks.

Inventory audit results

Analysis of mature volumes

The results of the inventory audit for mature volume statistical analyses at the 12.5+ cm dbh utilization limit for the total forested area are given in Table 1 (see Appendix A for the mature sample data).

	Audit Volume Estimate	Inventory Volume Estimate	Ground Attribute Volume Estimate
Number of Samples	50	50	50
Mean (m^3/ha)	269	277	264
Coefficient of variation (%)	40	35	38
Standard error (m^3/ha)	15.26	13.86	14.12
Sampling Error (%) at 95% confidence level	11.4	10.1	10.8
95% Confidence Interval (m^3/ha)	238–299	249–305	235–292

Table 1: Statistics for the audit volume, inventory volume and ground attribute volume estimates at 12.5 cm+ dbh utilization for Bulkley TSA.

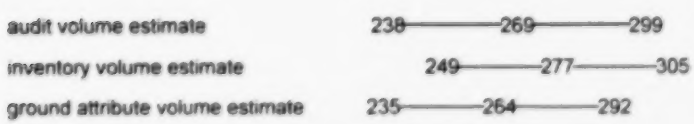

Table 2 Bar graph representation of 95% confidence intervals in m^3/ha

The calculated correlation coefficient of 0.274 for the audit and inventory volume estimates indicates a poor relationship among individual samples. There is an 8 m^3/ha difference between the means of the inventory estimate for mature volume (277 m^3/ha) and the audit estimate (269 m^3/ha). While this comparison shows there is no statistically significant difference, the poor correlation between the estimates indicates a high degree of variation at the individual polygon level.

Figure 1 provides a graphical representation of the total bias for the mature component of the total forested area. Although the total bias was not statistically significant, Figures 2 and 3 provide information on the model bias and the classification bias. The letter codes on the scatter plots correspond to the growth type groups for the polygons as assigned in the inventory (see Table 3). The correlation coefficient, the ratio and its confidence interval, and the results of the paired sample t-test accompany each graph.

Growth Type Group Letter code	Growth Type Group Species Composition	# of polygons
F	H (and HPI), H Decid.	1
H	B, BH, BS	35
I	pure S	1
J	SF, SH (and SC), SB	1
K	SPI, S Decid.	2
L	pure PI	2
M	PI F,	7
N	PI Decid.	1

Table 3: Distribution of growth type groups (as assigned by the inventory) for the mature sample polygons.

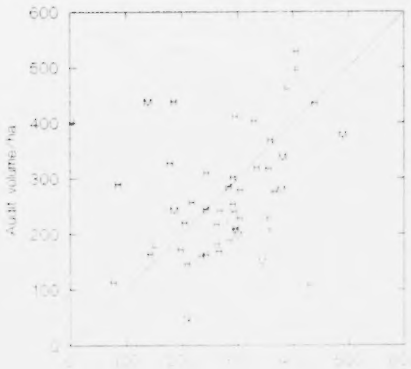

Figure 1: ***Total Bias*** Audit volume versus inventory volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.274**
(p-value* = 0.054)

Ratio of means = 0.97
95% confidence interval for ratio of means:
0.85 — 1.10

Mean difference (audit volume - inventory volume)
= -8.0 m^3/ha (p-value* = 0.650)

** a p-value* ***< 0.05*** *indicates statistical significance (at a 5% significance level)*

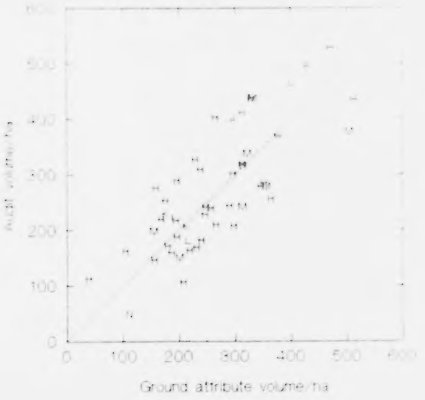

Figure 2: *Model Bias* Audit volume versus ground attribute volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.783**
(p-value < 0.001)

Ratio of means = 1.02
95% confidence interval for ratio of means:
0.95 — 1.09

Mean difference (audit volume - ground attribute volume)
= 5.2 m^3/ha (p-value = 0.594)

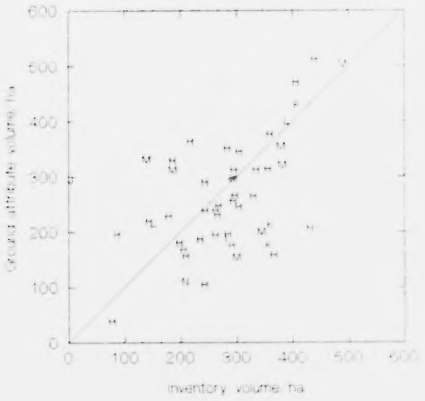

Figure 3: *Classification Bias* Ground attribute volume versus inventory volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.488**
(p-value < 0.001)

Ratio of means = 0.95
95% confidence interval for ratio of means:
0.85 — 1.05

Mean difference (ground attribute volume - inventory volume)
= -13.2 m^3/ha (p-value = 0.354)

Analysis of operable and inoperable volumes

To provide audit results more likely to be applicable to the timber supply planning process, an approximation was made of the forested areas considered currently available for timber harvesting (called *operable* areas). The audit results were post-stratified based on this approximation (see Appendices B and C for the operable and inoperable subsets of the mature sample data). The results from the operable forested area are summarized in Table 4. There were 18 of the 50 audit samples in inoperable forested areas. Because of the high variability and restrictive nature of conclusions associated with this small sample size, volume estimates from inoperable forested areas are not shown.

	Operable Audit Volume Estimate	Operable Inventory Volume Estimate	Operable Ground Attribute Volume Estimate
Number of Samples	32	32	32
Mean (m^3/ha)	285	311	289
Coefficient of variation (%)	34	28	32
Standard Error (m^3/ha)	17.04	15.50	16.42
Sampling Error (%) at 95% confidence level	12.2	10.2	11.6
95% Confidence Interval	250–320	280–343	255–322

Table 4: Statistics for the operable audit, inventory, and ground attribute volume estimates at 12.5cm+ dbh utilization for the Bulkley TSA.

audit volume estimate	250——285——320
inventory volume estimate	280——311——343
ground attribute volume estimate	255——289——322

Table 5: Bar graph representation of 95% confidence intervals in m^3/ha for the operable forested area.

For the 32 samples located within the operable forested area, the mean audit volume was 285 m^3/ha and the corresponding inventory volume was 311 m^3/ha. The difference of 26 m^3/ha between the mean audit volume and the mean inventory volume in the operable forested area was not statistically significant, 19 times out of 20. The sample size of 18 in the inoperable forested area was insufficient to allow any meaningful comparisons to be made.

Figures 4 to 6 provide a graphical representation of the total bias, model bias and classification bias for the operable forested area.

Figure 4: ***Total Bias for the Operable Forested Area*** Audit volume versus inventory volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.186**
(p-value* = 0.307)

Ratio of means = 0.92
95% confidence interval for ratio of means:
0.78 — 1.05

Mean difference (audit volume - inventory volume)
= -26.4 m^3/ha (p-value* = 0.214)

** a p-value **< 0.05** indicates statistical significance (at a 5% significance level)*

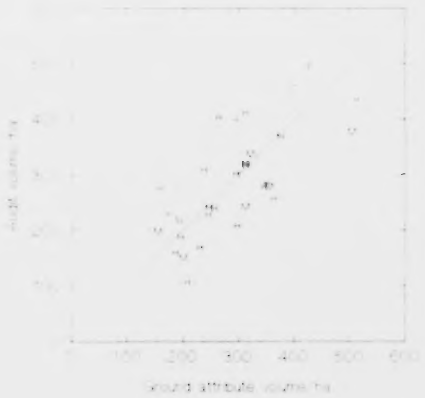

Figure 5: ***Model Bias for the Operable Forested Area*** Audit volume versus ground attribute volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.724**
(p-value < 0.001)

Ratio of means = 0.99
95% confidence interval for ratio of means:
0.90 — 1.07

Mean difference (audit volume - ground attribute volume)
= -4.0 m^3/ha (p-value = 0.748)

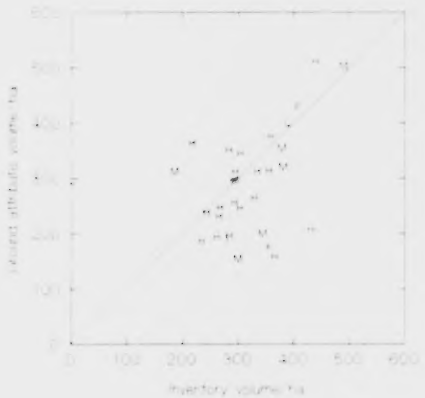

Figure 6: ***Classification Bias for the Operable Forested Area*** Ground attribute volume versus inventory volume, by inventory growth type group. Diagonal line represents a perfect correlation.

Correlation coefficient: **r = 0.357**
(p-value = 0.045)

Ratio of means = 0.93
95% confidence interval for ratio of means:
0.81 — 1.04

Mean difference (ground attribute volume - inventory volume)
= -22.4 m^3/ha (p-value = 0.226)

Analysis of mature species classification

The distribution of the growth type groups for the mature samples, as estimated by the inventory and by the audit, is provided in Table 6 (see Appendix D for a description of the species composition for each growth type group). Overall, 74% of the growth type groups assigned in the inventory matched the growth type group assigned in the audit.

Audit Growth Type Group	Inventory Growth Type Group											
	F	G	H	I	J	K	L	M	N	O	P	Total
F	***0***	0	0	0	0	0	0	0	0	0	0	0
G	1	***0***	1	0	0	0	0	1	0	0	0	3
H	0	0	***32***	0	1	0	0	2	0	0	0	35
I	0	0	0	***1***	0	1	0	0	0	0	0	2
J	0	0	2	0	***0***	0	0	0	0	0	0	2
K	0	0	0	0	0	***0***	0	1	0	0	0	1
L	0	0	0	0	0	0	***1***	0	0	0	0	1
M	0	0	0	0	0	0	1	***3***	0	0	0	4
N	0	0	0	0	0	0	0	0	***0***	0	0	0
O	0	0	0	0	0	0	0	0	1	***0***	0	1
P	0	0	0	0	0	1	0	0	0	0	***0***	1
Total	1	0	35	1	1	2	2	7	1	0	0	50

Table 6: Mature sample growth type group distribution for the audit and the inventory. The bold italic entries on the diagonal in the table indicate a growth type group match between the audit and the inventory.

A K statistic was used to compare the observed level of agreement (the proportion of growth type group matches) with the expected level of agreement. The calculated Z-value for the K statistic was 3.164. Since this value is greater than the critical Z-value of 1.645 (at a 5% significance level), the K statistic indicated a high level of agreement between the inventory growth type group classification and the audit classification. However, these results should be interpreted with care. The assessment of the mature inventory classification is based on broad species groupings (i.e. growth type groups). In addition, the sample sizes in the inventory audit are smaller than are usually recommended for application of the K statistic.

Analysis of immature inventory classification

Out of 20 stands sampled in the field, one stand was not assessed a site index because it was found to be a mature stand. Of the remaining 19 immature stands, the inventory correctly identified site index within ± 3 m of the audit site index for nine stands. The inventory site index was more than 3 m lower than the audit site index for nine stands, and more than 3 m higher for one stand. These results are illustrated in Figure 7 (see Appendix E for the immature sample data).

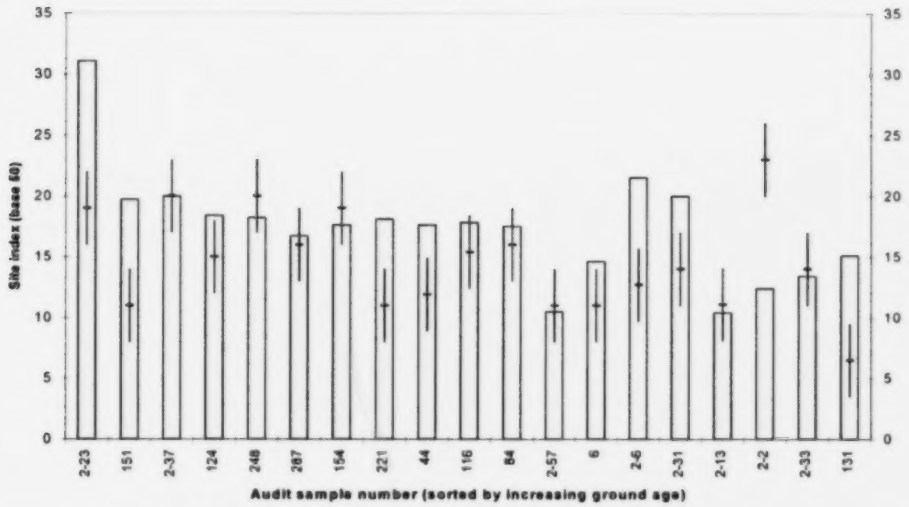

Figure 7: Comparison of audit and inventory site index values for immature stands. The shaded bars represent the audit site index. The tick marks on the vertical lines represent the inventory site index (the vertical lines have arbitrarily been set at ± 3 m around the inventory site index). The samples are sorted in order of increasing stand age, as estimated by the audit.

The distribution of the growth type groups for the 19 immature polygons, as estimated by the inventory and by the audit, is provided in Table 7. Overall, 26% of the growth type groups assigned in the inventory matched the growth type group assigned in the audit.

Audit Growth Type Group	Inventory Growth Type Group										
	H	I	J	K	L	M	N	O	P	Q	Total
H	***1***	0	0	0	0	4	0	1	0	0	6
I	0	***0***	0	0	0	0	0	0	1	0	1
J	0	0	***0***	1	0	0	0	0	0	0	1
K	0	0	0	***1***	0	0	0	0	0	0	1
L	1	0	0	0	***1***	2	0	0	0	0	4
M	0	0	0	0	1	***1***	0	0	0	0	2
N	0	0	0	0	0	1	***0***	0	0	0	1
O	0	0	0	0	0	0	0	***0***	1	0	1
P	0	0	0	0	0	0	0	0	***1***	0	1
Q	0	1	0	0	0	0	0	0	0	***0***	1
Total	2	1	0	2	2	8	0	1	3	0	19

Table 7: Immature sample growth type group distribution for the audit and the inventory. The bold italic entries on the diagonal in the table indicate a growth type group match between the audit and the inventory.

A K statistic was used to compare the observed level of agreement (the proportion of growth type group matches) with the expected level of agreement. The calculated Z-value for the K statistic was 1.996. Since this is greater than the critical Z-value of 1.645 (at a 5% significance level), the K statistic indicates a high level of agreement between the inventory GTG classification and the audit classification. As was indicated for the mature inventory classification, these results should be viewed with care.

Analysis of non-forest inventory classification

Thirty stands classified as non-forest were assessed for their inventory assignment accuracy. The resulting score was 87%, which meets the provincial minimum standard of 85% (see Appendix F for the non-forest assessment evaluation sheet).

Discussion and conclusions

The objective of the inventory audit in the Bulkley TSA was to assess the overall accuracy of the current (1974 and 1976, with a classification reinventory in 1988) Ministry of Forests inventory. The mature, immature and non-forest components were tested.

The results of the audit for the mature component of the inventory suggest that the inventory is statistically acceptable. However, the correlation between the audit and the inventory volumes is poor. This suggests a potential lack of consistency between the audit and inventory volume estimates. Conclusions regarding the acceptability of the inventory should be viewed with caution. The Bulkley TSA has undergone a new inventory since this audit took place. The new inventory will be assessed for accuracy using the information obtained by this audit.

Audit results for the immature component of the inventory suggest an acceptable level of accuracy for site index assignment in young stands. The audit assessment of the non-forest classification in the Bulkley TSA found it to be within provincial standards.

References

Cohen 1960. A coefficient of agreement for nominal scales. **Educational and Psychological Measurement**, 20(1):37-46.

Walpole 1974. **Introduction to Statistics**. 2nd edition. MacMillan Publishing Co. Inc., New York. 340pp.

Appendices

A Mature Sample Data

B Data for the Operable Subset of Mature Samples

C Data for the Inoperable Subset of Mature Samples

D Species Composition by Growth Type Group

E Immature Sample Data

F Non-forest Classification Evaluation Assessment

A Mature Sample Data

B Data for the Operable Subset of Mature Samples

C Data for the Inoperable Subset of Mature Samples

D Species Composition by Growth Type Group

Growth Type Group Letter Code	Growth Type Group Species Composition
A	pure F
B	FC and FCy, FH, FS
C	FPl, FPy, F Decid., Py, Pa
D	FL, Pw, LF, L
E	C, CF, CH
F	H (and HPl), H Decid.
G	HF, HC, HB, HS
H	B, BH, BS
I	pure S
J	SF, SH (and SC), SB
K	SPl, S Decid.
L	pure Pl
M	Pl F,
N	Pl Decid.
O	D Conif., A Conif.
P	D Decid., Mb, Bi, A Decid.
Q	Cot. Conif., Cot. Decid.

E Immature Sample Data

F Non-forest Classification Evaluation Assessment

Glossary

accuracy: A measure of the closeness of an estimate to the true value.

allowable annual cut: The rate of timber harvesting specified for an area of land.

analysis unit: The basic building block around which inventory data and other information are assembled for use in forest planning models. Analysis units represent the general level of aggregation, or detail, at which a timber supply analysis is carried out. They are normally defined by tree species and site qualities.

bias: The quality of a measurement device or procedures that tends to result in a systematic misrepresentation of what is being measured.

coefficient of variation: A relative measure of the variation of the population calculated as the ratio between the standard deviation and the mean value.

confidence interval: The range of values within which the population parameter is expected to lie.

confidence level: The stated probability that a population parameter lies within a given confidence interval.

correlation coefficient: A measure of the linear relationship between two variables. A value of 0 for the correlation coefficient indicates a random relationship whereas a value of ±1 indicates a perfect positive or negative linear correspondence.

diameter at breast height (dbh): The stem diameter (outside-bark) of a tree measured at breast height (1.3 metres above the point of germination) to the nearest millimetre.

field visitations: Ground level field procedures designed to provide physical verification of polygon inventory attributes.

free growing (crop): A crop of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees.

inoperable: Refers to areas having merchantable timber that cannot be harvested economically using current harvesting technology because of some physical barrier (such as a hanging valley), and to areas containing small patches of overmature timber surrounded by large areas of young stands.

K statistic: A test for statistical significance of agreement between nominal scale data. The K statistic is calculated as *(actual accuracy - expected accuracy) / (1-expected accuracy)*. The actual accuracy is estimated from the diagonal totals, and expected accuracy is estimated from the marginal totals, from the matrix of similarity (eg. a matrix of audit and inventory GTGs). The value of K is 1 when all elements are on the diagonal (i.e. perfect agreement), and less than 1 otherwise.

mean: The average value of a set of observations.

p-value: The probability associated with the result of a statistical test (eg. test of significant difference). The p-value represents the level of significance for the test; the smaller the value of this probability, the heavier the weight of the sample evidence.

pre-inventory assessments: Pre-inventory analyses are inventory activities to evaluate the existing forest inventory as the basis for deciding whether to re-inventory or update the current inventory, and to document the existing inventory, maps, and photos to support the execution of the reinventory or update if required.

ratio estimate: The ratio between two different estimates.

representative: The quality of a sample having the same characteristics as the population from which it is selected.

sampling: The process of selecting observations from a population.

sampling error: The error attributed to sampling procedures. It is computed as the standard error of an estimate multiplied by a value from the t distribution corresponding to a stated confidence level. Sampling error is often expressed as a percentage of the estimate (eg. percentage of the mean).

significant difference: An expression used in reference to the results of a statistical test in which either two or more estimates are compared or an estimate is compared to a fixed value. If the observed difference is greater than what might be expected as a chance occurrence due to the sampling procedures, the difference is said to be statistically significant.

site index: A measure of site productivity. Site indices are based on tree height as a function of stand age and are usually expressed graphically as site index curves. A number of site index curves have been developed for British Columbia's major commercial tree species.

standard error: An expression of the absolute variability of an estimate. It is computed as the standard deviation divided by the square root of the number of samples.

standard deviation: A measure of the absolute variation of the population.

timber supply analysis: The technical process of amalgamating land management information into computer systems that predict the amount of timber available for harvest over given time periods.

timber supply area: An integrated resource management unit established in accordance with section 6 of the *Forest Act*.

tree farm license: An integrated resource management unit established in accordance with section 28 of the *Forest Act*.